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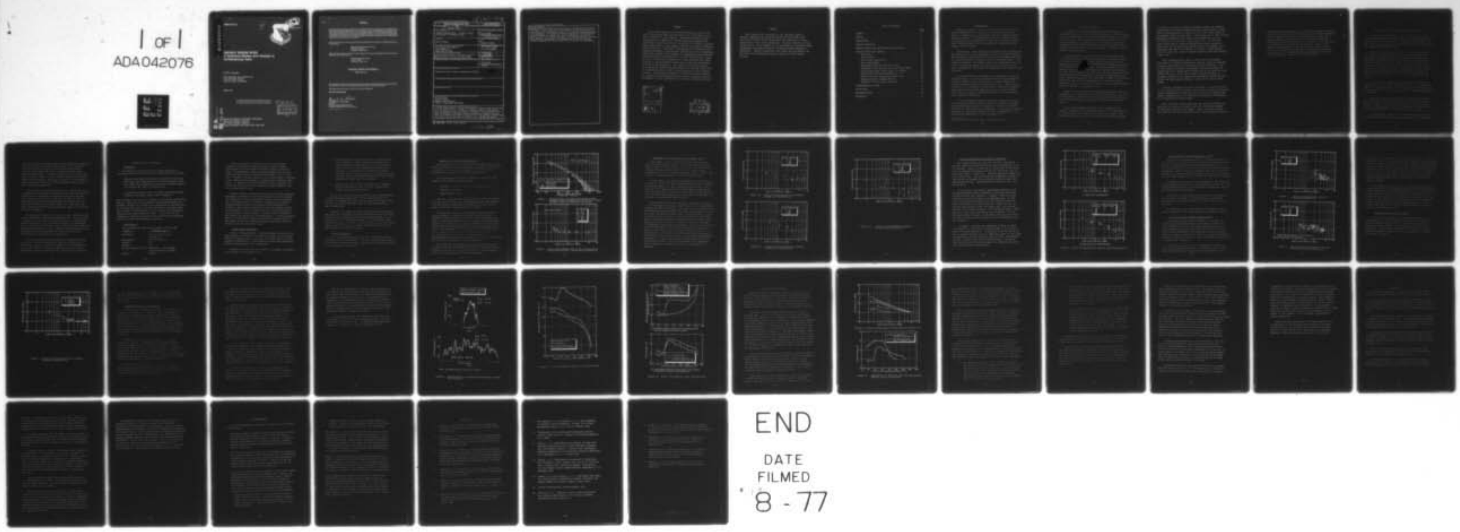

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AIRCRAFT SIDELINE NOISE
A Technical Review and Analysis of Contemporary Data

DAVID Q. WALKER

BOLT BERANEK AND NEWMAN INC.
21120 VANOWEN STREET
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APRIL 1977

Approved for public release; distribution unlimited

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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This report presents a review and analysis of recent aircraft flyover data where the aircraft is at a low angle of elevation relative to the observer. Excess attenuation factors (attenuation in addition to normal spherical divergence and atmospheric absorption losses), evaluated for a range of aircraft types, were found to vary between aircraft and could be generally characterized as a function of aircraft angle of elevation only. Fuselage shielding or installation effects could not be positively identified although their presence → next page

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is suggested by the differing excess attenuation characteristics of each aircraft type. Lack of detail in the data available for review precluded the identification of any propagation losses due to turbulent scattering of sound in the atmosphere. The results of the study suggest that currently applied predictive models for sideline noise tend to overestimate noise levels - particularly for 3 and 4 engine aircraft. An alternative approach to sideline noise prediction is suggested and recommendations are made to encourage technical development in this uncertain area of aircraft noise prediction.

SUMMARY

This report presents a review and analysis of recent aircraft flyover data where the aircraft is at a low angle of elevation relative to the observer. Excess attenuation factors (attentuation in addition to normal spherical divergence and atmospheric absorption losses), evaluated for a range of aircraft types, were found to vary between aircraft and could be generally characterized as a function of aircraft angle of elevation only. Fuselage shielding or installation effects could not be positively identified although their presence is suggested by the differing excess attenuation characteristics of each aircraft type. Lack of detail in the data available for review precluded the identification of any propagation losses due to turbulent scattering of sound in the atmosphere. The results of the study suggest that currently applied predictive models for sideline noise tend to overestimate noise levels - particularly for 3 and 4 engine aircraft. An alternative approach to sideline noise prediction is suggested and recommendations are made to encourage technical development in this uncertain area of aircraft noise prediction.

PREFACE

This research was performed for the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio under Project/Task 723104, Measurement and Prediction of Noise Environments of Air Force Operations. Technical monitor for this effort was Mr. Jerry Speakman of the Biodynamic Environment Branch, Biodynamics and Bionics Division, Aerospace Medical Research Laboratory. Partial funding for this effort was provided by the Air Force Civil Engineering Center, Tyndall Air Force Base, Florida.

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INTRODUCTION

When an aircraft is on or close to the ground, the noise levels experienced by an observer are generally lower than would be experienced if the aircraft were at a similar distance directly overhead. This additional attenuation which cannot be accounted for by propagation losses due to spherical divergence (inverse square law) and atmospheric absorption is the subject of this review.

Historically, noise prediction procedures have accounted for attenuation due to sound propagation close to the ground surface, and shielding or installation effects for multi-engined aircraft, by somewhat uncertain empirically based prediction models. This situation persists even though it has been demonstrated that the choice of empirical models for sideline noise prediction may have a significant effect upon the resulting noise contour levels and areas.

In the interests of providing a more substantial technical foundation and, as a result, improved predictive procedures for aircraft sideline noise, this technical review examines and collates available aircraft sideline noise data. The principal objective is to stimulate the development of empirical prediction models from a broader data base, and to provide initial direction for studies to encourage progress to be achieved in this technically weak area.

It is anticipated that this study will complement, rather than review, previous technical efforts to describe, quantify, and mathematically explain the phenomena involved in aircraft sideline or overground noise propagation. Discussions on previous work and the conclusions drawn from them are available in the appropriate comprehensive review documents.[1,2] *

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* References are listed at the end of this report.

PROBLEM DISCUSSION

In terms of a technical understanding of the physical phenomena involved, the most uncertain element in the prediction of noise from air base and airport operations relates to aircraft sideline noise. This uncertainty is in the estimation of the sound attenuation, in addition to losses caused by spherical divergence and atmospheric absorption, that is apparent when an aircraft is on the ground or at a low angle of elevation with respect to the observer.

This attenuation, which results in lower aircraft noise levels than would be normally anticipated, is commonly referred to as extra or excess ground attenuation (EGA) and has been exhaustively discussed in both qualitative and sometimes speculative terms for a number of years. To date, however, firm conclusions have yet to be drawn upon the relative significance of the many varied physical phenomena that are potentially involved. The reflection and absorption of sound by a ground surface of finite acoustic impedance, the scattering of sound by a turbulent atmosphere, and acoustic shadowing due to thermal and wind gradients close to the ground are some of the popularly discussed phenomena thought to contribute to EGA.

While the most significant contributing factors to EGA are considered to be a direct result of sound propagation close to the ground surface, installation effects also provide the potential for differences between overhead and sideline aircraft noise levels.

When a multi-engined aircraft is at a relatively low angle of elevation, the possibility exists for the observer to be shielded from noise from one or more of the engines. The shielding may be a result of the intervening aircraft fuselage,

or it may be a source interaction mechanism where, for example, side-by-side jet nozzle configuration may cause changes in noise source characteristics, or cause one jet to act as an effective aerodynamic shield for the other. When either one or more of these phenomena are present, the result is an assymetric radiation pattern around the aircraft longitudinal axis. Collectively these factors may be termed an installation effect, causing a noise level to the side of an aircraft which is different, and generally lower due to the nature of aircraft configurations, than the noise level that is measured directly under the aircraft flight path.

Thus, available data, none of which have been acquired specifically to examine installation effects, cannot be reviewed to assess contribution of installation effects directly. This is particularly true since the maximum intuitive estimates of attenuation due to installation effects are on the order of 3 dB (EPNdB, SEL, etc.) while the reported cumulative effects of phenomena related to low angle sound propagation (which may well include any installation effects) may be 10 to 15 dB or even higher.

However, available data may be reviewed to establish trends in the collective EGA function, with the aim to resolve from these trends characteristics which may be a function of aircraft type, thereby suggesting (but not necessarily confirming) the presence of an installation related effect.

Most aircraft flyover data that are readily available are presented in noise units which result from a complex analysis of the basic physical sound signal. These units (for example SEL, EPNL and PNL) are generally overall noise measures involving

an appropriate frequency weighting relating to subjective response, and may include some form of time integration and possibly penalties for the presence of tones in the noise signature. Thus, while working, empirical relationships may be derived for EGA (including any installation effects) it is difficult if not impossible to determine from available data the relative changes in the physical characteristics of the flyover noise signatures which give rise to this excess attenuation. This detailed information is essential if the significant physical mechanisms involved in EGA and installation effects are to be identified.

CURRENT METHODS FOR SIDELINE NOISE PREDICTION

Comprehensive descriptions of the alternative procedures for modeling the EGA and installation effects in aircraft sideline noise prediction are available.[3] However, it is worthwhile in the context of this review to describe briefly and qualitatively the approaches that may be taken.

Based on experimental data, [4,5] EGA may be quantified as a function of both frequency and distance. Thus, appropriate attentuation factors in addition to spherical divergence and atmospheric absorption losses may be applied to the base aircraft noise data prior to the computation of AL, ALT, or PNL and PNLT, as a function of distance from the source to receiver. SEL and EPNL functions may then be determined. The civil NEF[6] and CSIR (South African) procedures adopt this approach, as does the NOISEMAP procedure used by the Air Force, Navy, EPA and NASA.

Collective data trends of EGA in terms of EPNL (or SEL) may be used to derive the attenuation directly as a function of source to receiver distance. This method was once proposed, but at the present time has not been adopted nor formally recommended, by the SAE.[8]

Both of the above approaches predict EGA under conditions where the source and receiver are located nominally at ground level. No matter which physical mechanism(s) are principally involved in EGA, measured data trends indicate a decreasing EGA with increasing observer to aircraft angle of elevation.

For this reason, some form of transition function must be provided such that at and above a specified angle of elevation

only the standard spherical divergence and atmospheric absorption propagation losses are taken into account. This transition function has been a subject of much discussion, with the principal topic being the angle of elevation at which EGA becomes insignificant. Candidate angles for this cutoff point range between 6 degrees[7] and 30 degrees[8] and on some opinions, higher than 30 degrees. The angles selected or recommended are generally a strong function of the particular source of data used in their determination.

The question of installation effects (or shielding), if it is addressed in the noise prediction process, has been treated separately and in addition to functions to account for EGA. One assumption, provided for review by the SAE[8], is that for multi-engine aircraft the maximum potential benefit from installation effects is 3 dB (SEL, EPNdB, etc.) and that this value diminishes with increasing elevation angle to zero at 90° (directly overhead).

Thus, whichever approach is taken to predict sideline noise levels, the method includes many uncertainties. This situation is borne out by the lack of uniform opinion on the appropriate predictive approach, and the relative absence of experimental data to allow even a preliminary rank ordering of the significant contributing phenomena to EGA. Likewise, the identification and separation of EGA and installation effects has yet to be accomplished in actual aircraft flyover data.

Noise contour sensitivity studies[8] have demonstrated that the choice of prediction model for aircraft sideline noise prediction can have a significant impact on the resulting contour areas. This fact further endorses the need for a more substantive technical foundation for sideline noise prediction.

AIRCRAFT NOISE DATA REVIEW

Objectives

The purpose of this review is to bring together in a consistent way aircraft flyover noise measurements that include:

. Sideline data where simultaneous measurements have been made under the flight path and at varying distances from the flight track, emphasizing data where aircraft angles of elevation are small (30° and below),

. A variety of aircraft types including large multi-engine transport and single engine combat equipment,

and to examine these data for evidence of EGA and/or installation effects. While much of the data has been presented before in technical reports, it is felt that a comparison of the data sets on a similar basis and at one time represents a valuable first step towards the development of a more refined and technically based sideline noise prediction model. To the best of our knowledge, a broad data review of this type has not been undertaken or at least made available previously.

Data Sources

The following data have been reviewed in this study:

Source	Aircraft Type
Hydrospace[9]	A-7, F-4, F-101, A-6, Learjet, DC-9
Hydrospace[10]	727, 707, KC-135A
Boeing[11]	727
Boeing[12]	727
British Aircraft Corp.[13]	Principally multi-engine turbojet powered aircraft
Douglas[14]	DC-8-61

With the exception of the BAC data, all the reports referenced have presented data in terms of EPNL (or EPNL differences) versus aircraft to observer range or elevation angle. Altitudes have typically ranged between 200 feet and 9,000 feet with sideline measurement distances of up to 9,000 feet. Aircraft elevation angles at the closest point of approach to the observer range between 2.5 degrees and 90 degrees (overhead). In general, the data reviewed have been acquired over relatively open terrain with microphone heights between 4 and 6 feet above ground level.

Recent technical evaluations both by Boeing (and subsequent reanalysis of Boeing data by United Airlines), BAC and Douglas have suggested a strong correlation between excess attenuation and the aircraft angle of elevation relative to the observer - notwithstanding the distance between the aircraft and the observer. Since similar trends were initially visible in data from Hydrospace, this correlating approach (excess attenuation versus aircraft elevation angle at closest point of approach) was used in the analysis of the flyover data. It was anticipated that if the excess attenuation was indeed a strong function of both angle and distance then any distance dependence would be evident in the resulting data plots.

Source Data Limitations

Any set of measured data contains limitations either in the detail which is provided in the technical report or, as authors generally recognize where necessary, in certain aspects of data quality or completeness. Cross analysis between data from these reports merely preserves the limitations.

However, two steps have been taken in an attempt to minimize the inclusion of questionable data:

(1) Flyover data with high engine thrust conditions have been emphasized. Higher power settings are most easily reproduced under varying test conditions and have been the most comprehensively reported engine settings in the data sets available for review. Further, these conditions are generally associated with the best flyover to background noise ratio-particularly important at large sideline distances.

(2) Where flight path tracking information is available with the noise data, data sets with inconsistent flight paths have been omitted.

All the data reviewed are from sources which presented data in subjective noise units, EPNL or PNL, and thus it is not possible to determine from the data the physical changes in the flyover noise signatures that result in the presence of an excess attenuation.

However, even though the basic source data are in subjective units, one set of flyover spectral time histories has been made available from overhead and sideline microphones where an excess attenuation of 8-11 EPNdB was apparent. These data have been reviewed in detail to determine in an initial, but not necessarily general, way the changes in flyover signature which result in this significant excess attenuation.

Data Presentation

In the following paragraphs, the data selected from each information source are presented. The test programs and original data form are described briefly, together with appropriate comment on the approach to re-analysis.

Hydrospace Seventeen Aircraft Study[9]

Data reported in this study comprise aircraft flyover noise levels presented in EPNL as a function of aircraft altitude (200 to 6,000 feet) and sideline distance (110 to 3,500 feet). Microphones were located 4 feet above ground level.

The following data from this Hydrospace study have been extracted for analysis in this review:

- Aircraft - A-7, F-4, F-101, A-6, Learjet, DC-9
- Altitude - 200 feet
- Engine thrust - 100%.

This data selection was based upon the need for relatively complete and consistent sets of measurements for each aircraft at a well defined engine power setting, and to give a good range of aircraft elevation angle (3° to 50°).

Standard noise level versus distance curves for air-to-ground propagation (spherical divergence and atmospheric absorption losses only) based upon data acquired by AMRL were used as a reference against which to compare the measured data. Offsets due to aircraft speed and other effects are normalized by best fitting the standard curve to the measured data at the smaller slant distances. Good agreement was obtained between aircraft data and the noise level versus distance curves at slant ranges below 1000 feet. Figure 1 shows this comparison process for the F-101 flyover data and the method by which excess attenuations were established.

This procedure for analysis was followed for each of the aircraft noted, and in Figure 2, the excess attenuation for each aircraft is presented as a function of the aircraft elevation angle at the closest point of flyover approach.

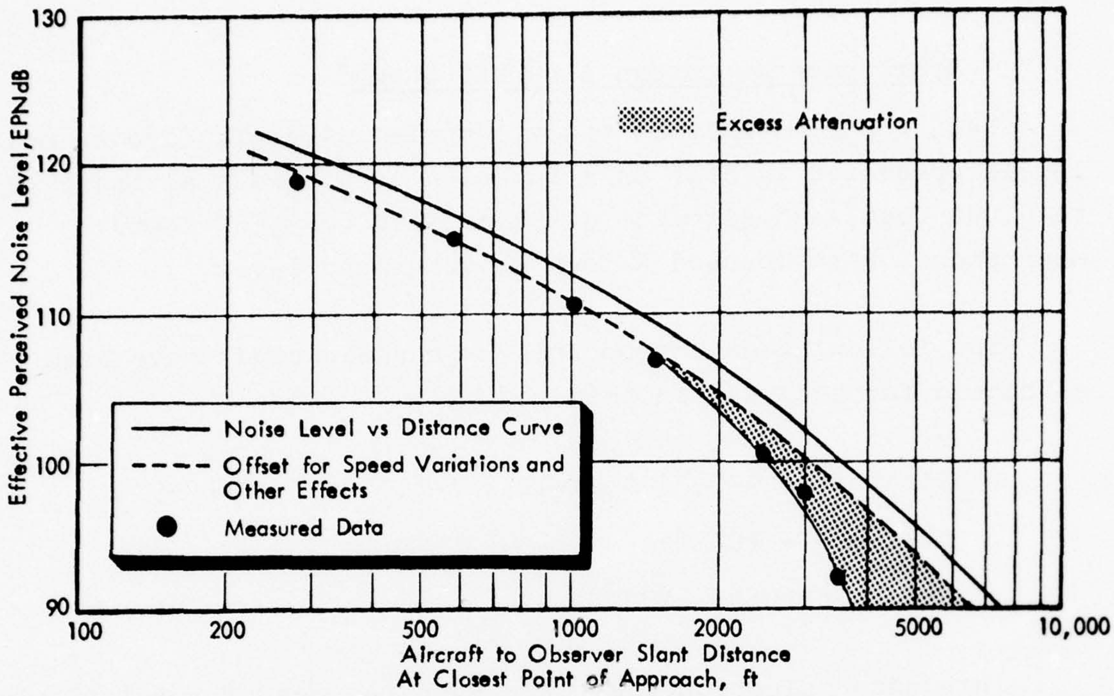


FIGURE 1. DETERMINATION OF EXCESS ATTENUATION FROM MEASURED DATA AND REFERENCE NOISE LEVEL VERSUS DISTANCE CURVES (HYDROSPACE F-101 DATA)

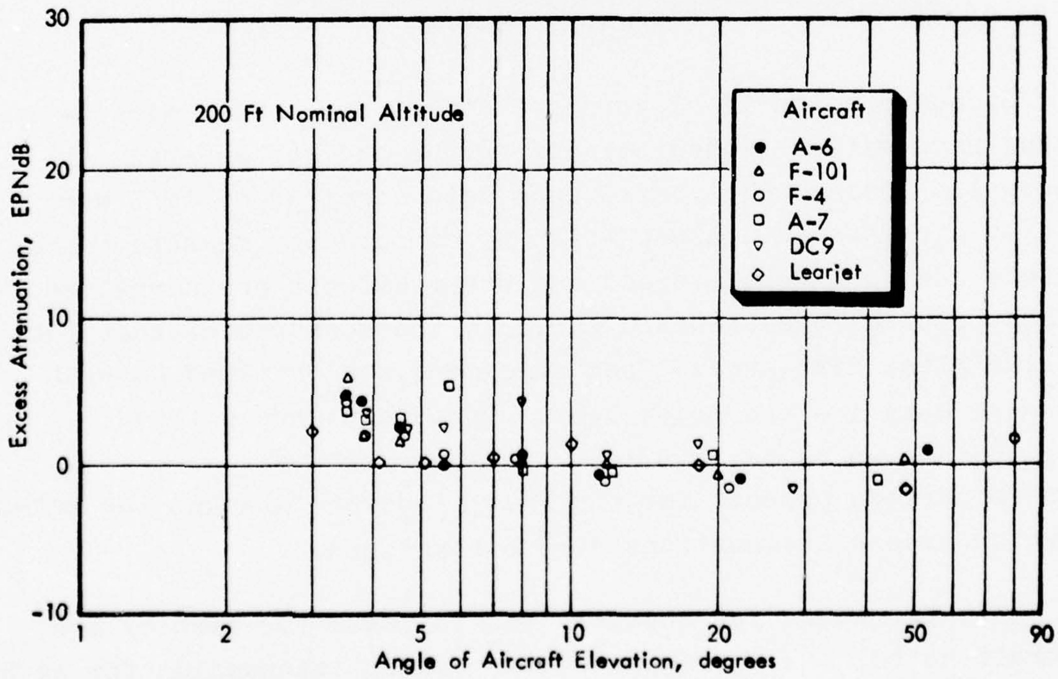


FIGURE 2. EXCESS ATTENUATION —A-6, F-101, F-4, A-7, DC-9 AND LEARJET AIRCRAFT (HYDROSPACE REFERENCE 9)

Hydrospace Four Aircraft in Level Flight Study[10]

This series of tests, undertaken at National Aviation Facilities Experimental Center, resulted in extensive level flyover data for four aircraft -- 727, 707, DC-9 and KC-135A Aircraft altitudes ranged from 250 ft. to 4,000 ft. with microphones located at sideline distances between 250 ft. and 7,000 ft. Microphones were 4 feet above ground level.

In the report, the author acknowledges the elimination of a number of 7,000 feet sideline measurements due to the presence of excessive ambient or data acquisition system noise. The question of the impact of fairly strong negative wind vectors (from the microphone towards the source) was also discussed in the report with particular regard to specific KC-135A data. No positive conclusions were drawn however.

Data extracted from this Hydrospace study for the purpose of this reanalysis and review comprise the 727, 707 and KC-135A aircraft at 100% rated thrust. DC-9 data are not reviewed due to significant vertical dispersion in flight paths during the tests. The 4,000 foot altitude flyover data for all aircraft is likewise omitted due to lateral dispersion during the test flights. Again, the measured data are compared with the standard air-to-ground noise level versus slant distance curves to determine the magnitude of any excess attenuation. For the three aircraft, these attenuations are presented as a function of elevation angle at the closest point of aircraft approach, Figure 3. In this analysis, since data from each aircraft may be presented separately (in the previous Section a collective comparison was necessary), the data have not been normalized with the noise level versus distance curves at the smaller slant distances. This is evident by slight data offsets at high angles of elevation.

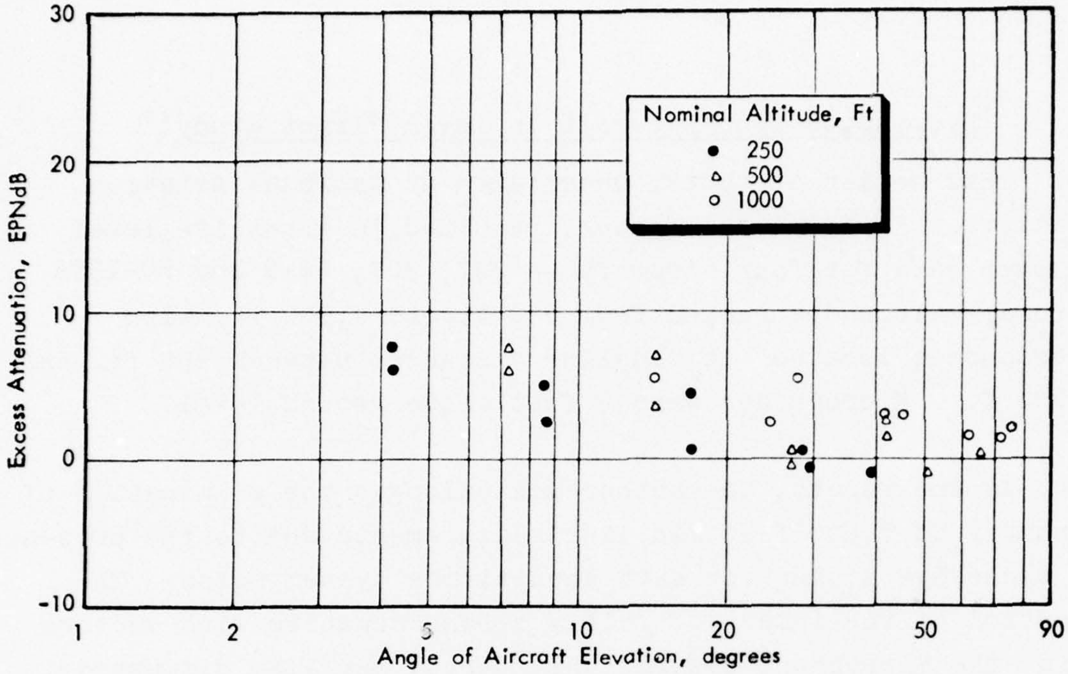


FIGURE 3(a). EXCESS ATTENUATION—707-320B AIRCRAFT (HYDROSPACE REFERENCE 10)

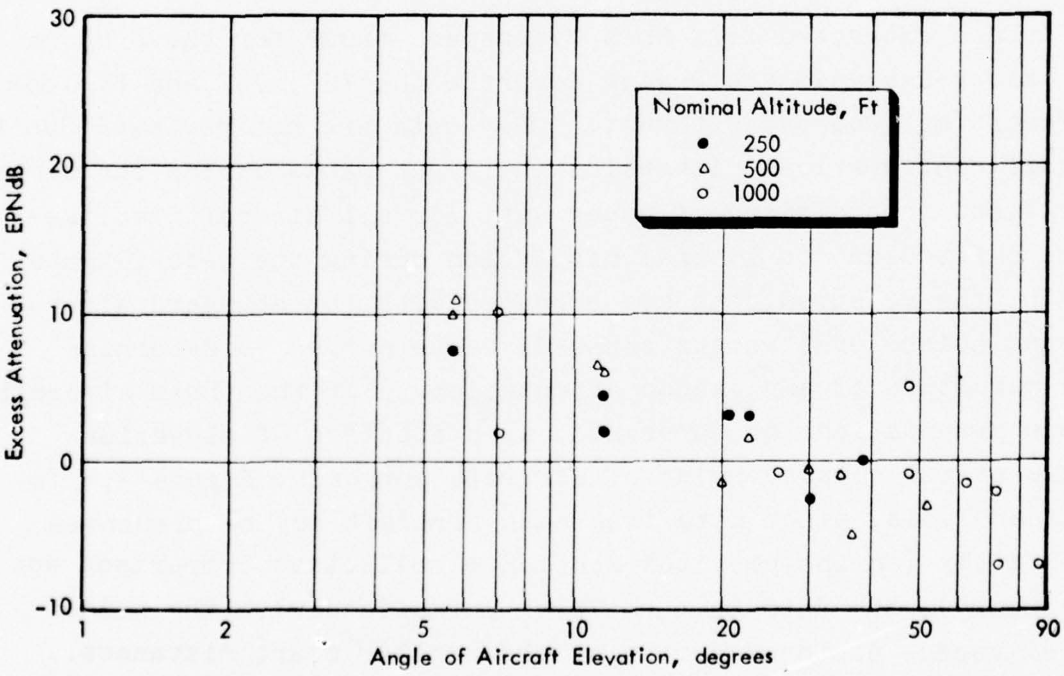


FIGURE 3(b). EXCESS ATTENUATION—KC-135A AIRCRAFT (HYDROSPACE REFERENCE 10)

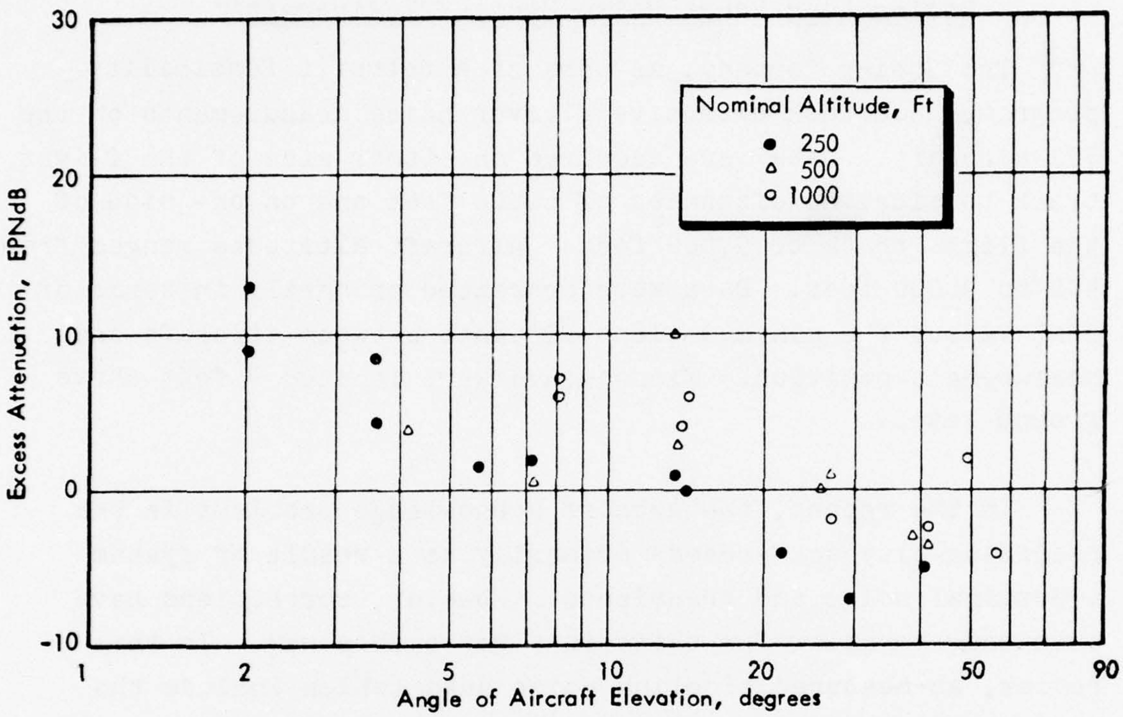


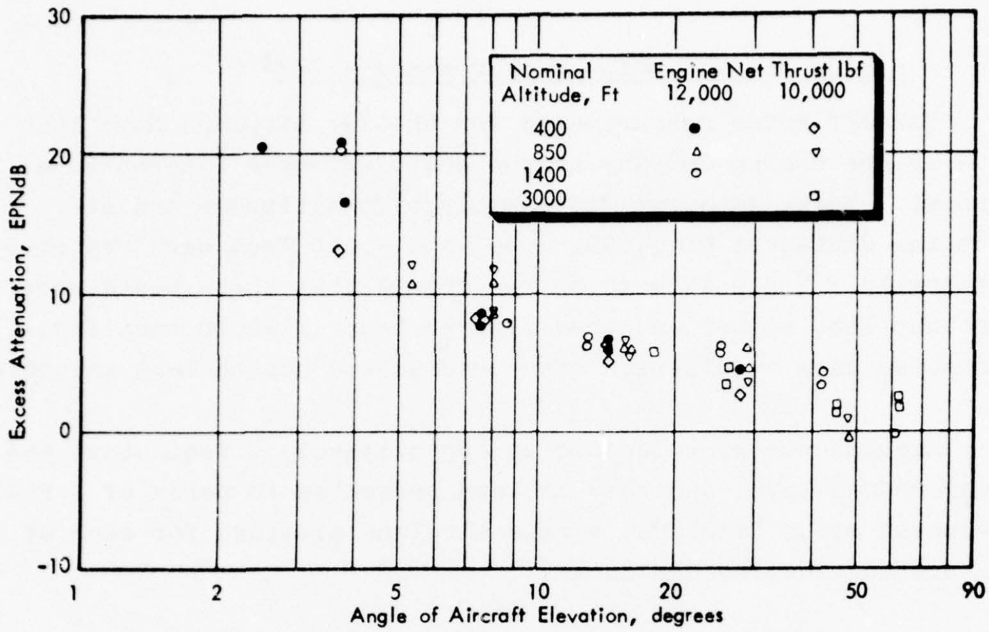
FIGURE 3(c). EXCESS ATTENUATION—727 AIRCRAFT (HYDROSPACE REFERENCE 10)

Boeing Long Range Noise Study-727 Aircraft[11]

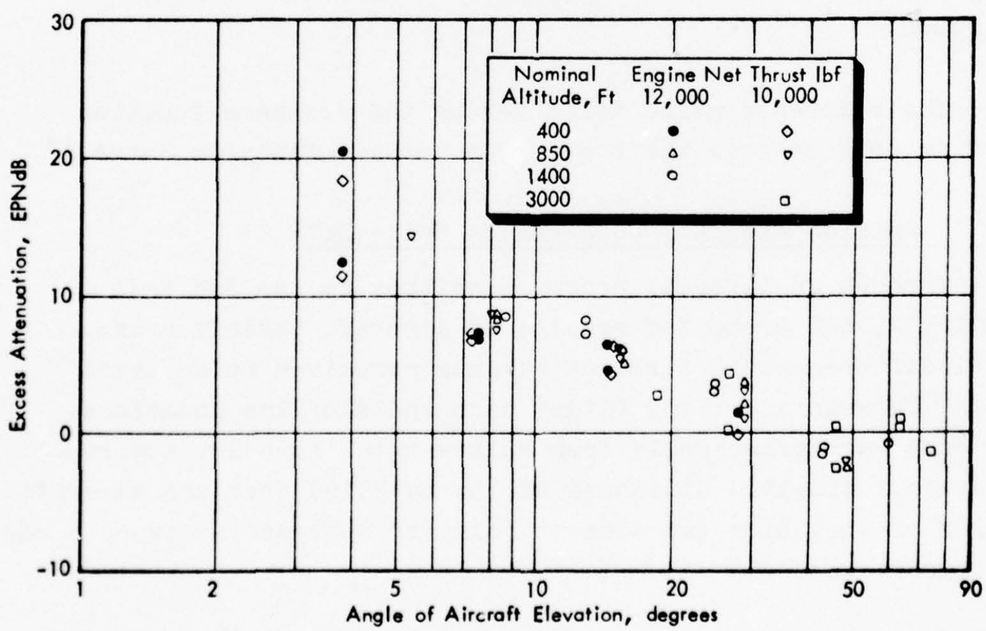
The Boeing Company, as part of a retrofit feasibility program, undertook extensive flyover noise measurements on the 727 aircraft. Data were acquired on either side of the flight track to sideline distances of 6,000 feet and on one side of the flight track to 9,000 feet. Aircraft altitudes ranged from 400 to 9,000 feet. Data were presented primarily in terms of EPNL versus the minimum slant distance between aircraft and measurement position. Microphones were located 4 feet above ground level.

In the report, the authors acknowledge problems in the recording/playback process primarily as a result of system electrical noise and transients. However, corrections have been made to allow for these in a reasonable way. In this review, as-measured sideline noise data (which include the basic corrections for system noise) are compared to the as-measured data acquired under the flight path. For the same aircraft to microphone distance, this comparison gives a direct measure of any excess attenuation at the sideline location. Two engine power settings (12,000 and 10,000 lbf. net thrust) and both the baseline and retrofit nacelle configuration data were analyzed.

In Figure 4, the data are presented in terms of excess attenuation as a function of elevation angle at the closest point of aircraft approach. It should be noted at this point, that a similar analysis has been undertaken prior to this study by Coykendall of United Airlines using the final standardized baseline airplane data from the Boeing study. The curves resulting from the UA analysis agree, not unexpectedly, with the derived curves of this review.



(a) BASELINE 727 CONFIGURATION



(b) QUIET NACELLE 727 CONFIGURATION

FIGURE 4. EXCESS ATTENUATION—727 AIRCRAFT (BOEING REFERENCE 11)

Boeing SEA-TAC Noise Measurements - 727[12]

Takeoff noise measurements for the 727 airplane have been made by the Boeing Company at the Seattle/Tacoma International Airport. Noise data for various aircraft altitudes and at sideline distances of 1,800, 2,900 and 4,000 feet were reported informally. While it must be recognized that these tests were somewhat less controlled than flyover tests planned specifically for noise data acquisition, the results are nonetheless valuable.

Microphones were located at approximately 5 feet above the local ground level and results were presented in terms of Δ EPNL (Overhead minus Sideline) versus airplane altitude for each of the stated sideline distances.

The results of these Boeing tests have been reviewed and are presented on Figure 5 in terms of excess attenuation against angle of aircraft elevation at the closest point of approach.

The reference noise level versus the distance function used in this case is the Boeing/FAA noise definition curve.[15]

British Aircraft Corporation Noise Data[13]

Through an informal report submitted to the SAE A-21 Committee, BAC presented results of aircraft takeoff noise level differences (in terms of maximum perceived noise level [PNLM]) between under the flight path and sideline locations. The data were principally from multi-engine turbojet powered aircraft. Sideline distances of 750 to 2,100 feet and aircraft angles of elevation (at closest point of approach) between 8 and 75 degrees were reported.

Review of these BAC data is somewhat more complicated since the shielding corrections (in accordance with the once proposed SAE ARP 1114 procedure)[8] had been applied to the

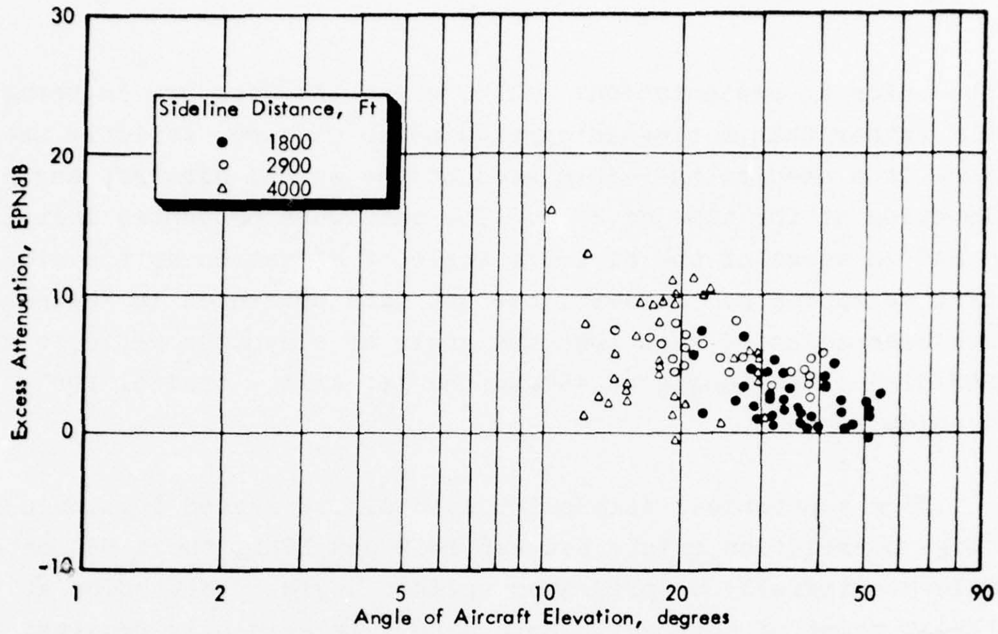


FIGURE 5. EXCESS ATTENUATION—727 AIRCRAFT (BOEING REFERENCE 12)

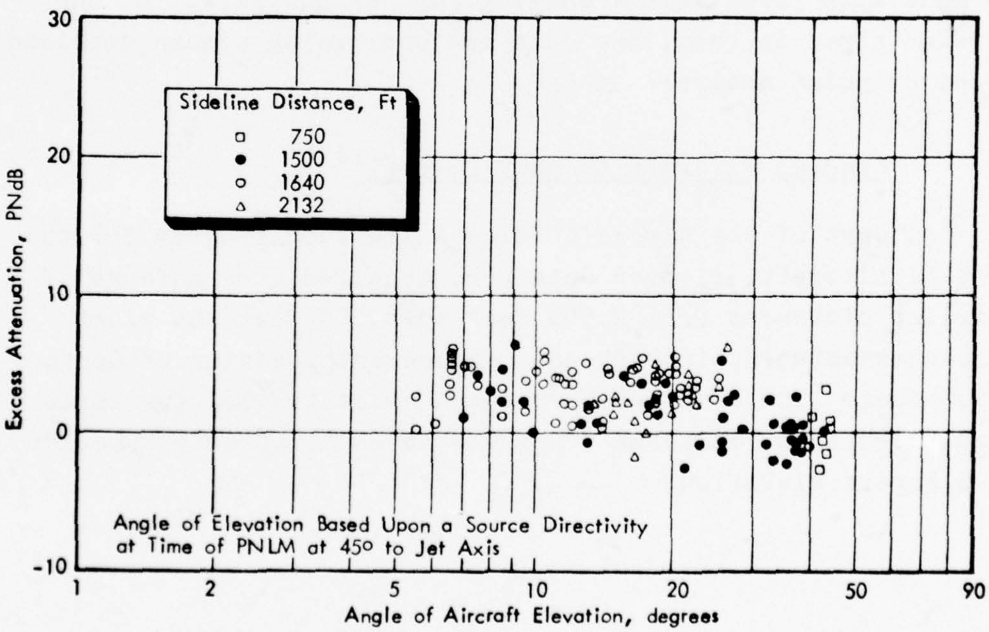


FIGURE 6. EXCESS ATTENUATION—(BRITISH AIRCRAFT CORPORATION DATA REFERENCE 13)

data prior to presentation. Also, since the data are in terms of PNLM rather than a time-integrated noise measure, strictly speaking there is a need to take into account the actual aircraft angle of elevation at the time of PNLM. The data were presented initially by BAC in terms of the aircraft angle of elevation at the closest point of approach. However, the BAC data presented in Figure 6 have been adjusted such that the angle of elevation reflects a PNLM directivity angle of 45° to the jet axis - typical for turbojet engines.

From a practical standpoint it could be argued that, since a high correlation exists between PNLM and EPNL, these BAC data could meaningfully be presented against angle of elevation at the closest point of approach. More detail is evidently required before the data can be fairly evaluated in terms which are comparable to the other data in this study and their presentation is made with reservations pending further analysis. At the present time, in fact, the data are undergoing a more detailed point by point analysis at BAC.

Douglas Aircraft Company DC-8-61[14]

As part of the Aircraft Noise Definition program for the DC-8-61 aircraft, flyover data were acquired over a range of sideline distances from 2,500 feet to 8,000 feet and slant distances between aircraft and measurement position of up to 9,900 feet. The data were presented collectively, for three thrust settings, in terms of excess attenuation as a function of aircraft elevation.

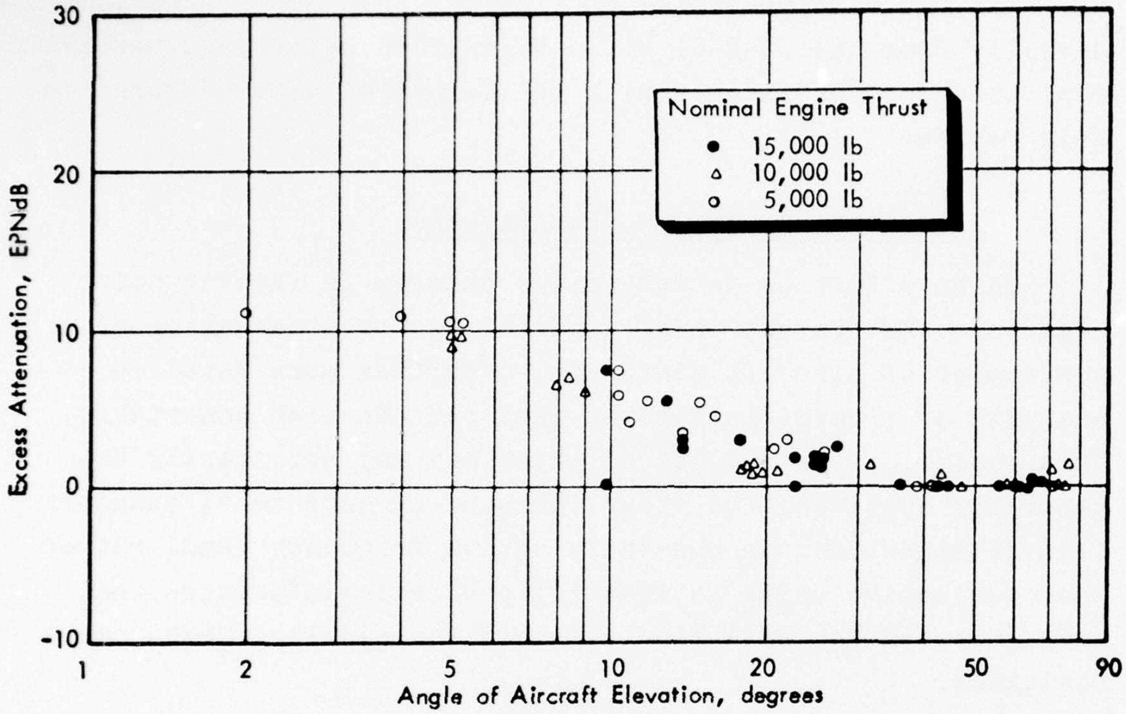


FIGURE 7. EXCESS ATTENUATION—DC-8-61 AIRCRAFT (DOUGLAS REFERENCE 14)

The DAC data presented on Figure 7 have been extracted directly from the DC-8-61 Noise Definition Report and merely replotted for consistency with the format of other figures in this review.

Additional Flyover Noise Analysis

In an effort to determine the changes in flyover noise signature that result in an apparent excess attenuation at low angles of aircraft elevation, a further more detailed analysis of a specific flyover data set has been undertaken. This analysis, the results of which may not necessarily be generally applicable to other independent data sets, examines flyover signatures in one-third octave frequency bands rather than subjective units to identify physical differences that exist between the data from overhead and sideline measurement positions.

The aircraft is a 727 in level flight at a nominal altitude of 800 feet. Measurements were acquired directly under the flight path and at symmetric points on either side of the flight track at 6,000 foot distance, representing an aircraft elevation angle of approximately 7.5°. When normalized for losses due to spherical divergence and atmospheric absorption, the sideline noise levels were 8.7 and 10.9 EPNdB lower than data under the aircraft flight path.

The time-integrated one-third octave band spectra from each measurement position may be compared to provide an indication of the difference in physical characteristics of the flyover signatures at each position.

The time integral approach is favored since, where large propagation distances are involved, the direct comparison of instantaneous peak spectral levels to determine attenuation may be severely influenced by short term SPL fluctuations and directivity effects.

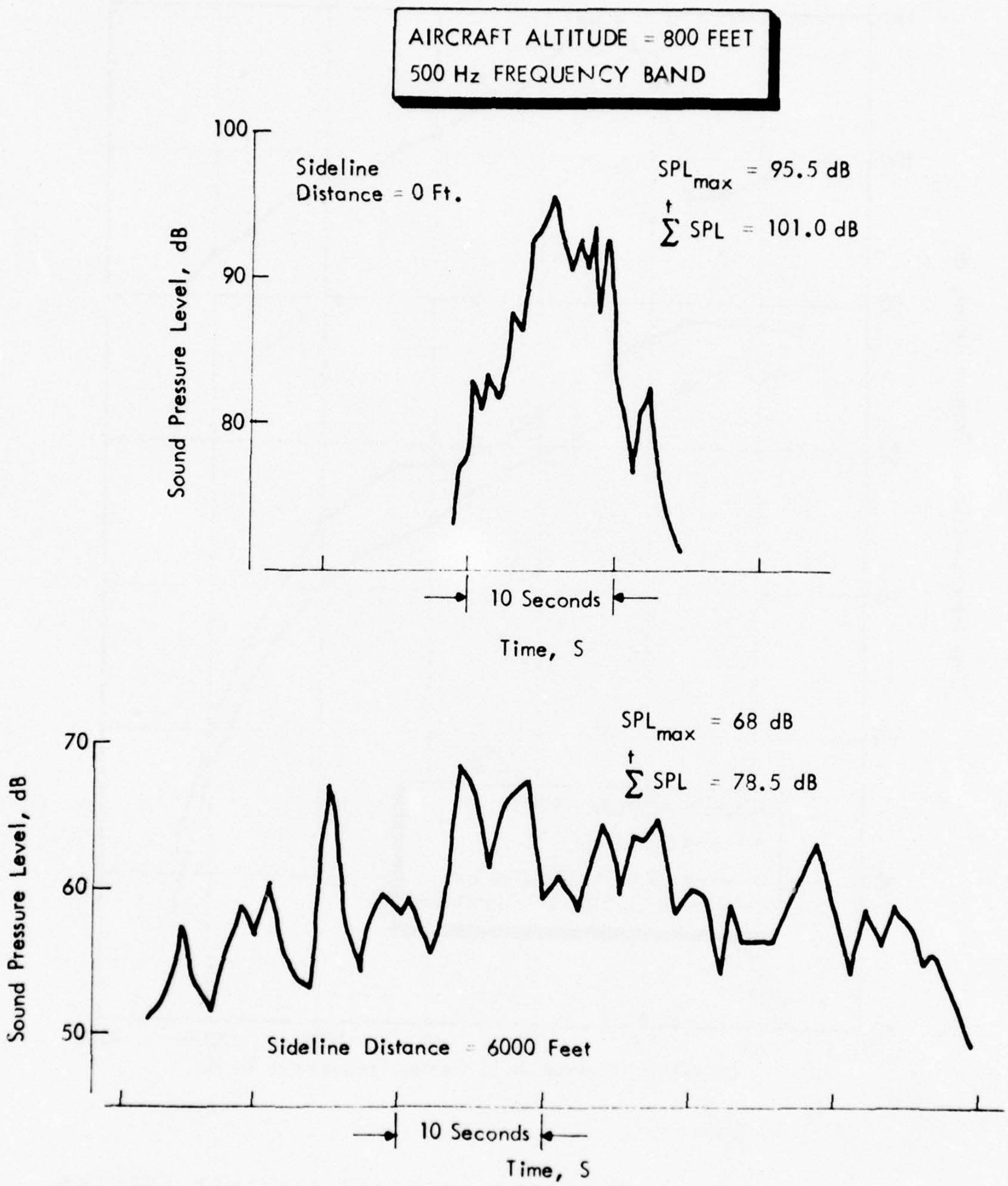
Representative one-third octave band sound pressure level time histories for the flyover event are presented on Figure 8; the maximum SPL during the event and time integrated band level are identified. Figure 9 shows the time integrated spectra from each of the three flyover measurement positions up to a frequency of 2500 Hz. at which point the distant sideline measurements are either at or below the background noise level. The consistent difference between the two sideline measurement positions (essentially independent of frequency) is interesting to note although no explanation for the asymmetry is presented herein. Not unexpectedly, the average difference of approximately 4 dB between the two sideline spectra was clearly reflected in an EPNL difference of 3.9 EPNdB at the two measurement positions.

For this analysis, the averaged sideline time integrated spectra are compared to the overhead spectrum, extrapolated to a 6,000 foot distance using standard air-to-ground propagation methods (spherical divergence, atmospheric absorption, and duration). The comparison may then be made between the measured "sideline" and the extrapolated "overhead" spectra to determine the unaccounted for attenuation that gives rise to the so-called excess attenuation or EGA. This comparison is shown in Figure 10.

For an ideal flyover noise event (a "triangular" time history), the numerical difference between the time integrated level and the instantaneous peak level increases by 3 dB per doubling distance from the source. The calculated attenuation curve of Figure 10(a) incorporates this assumption.

The actual differences between the time integrated and peak levels have been determined for each frequency band in the flyover data set and where this difference deviates from the ideally expected value (8.8 dB [10 log 6000/800]) an adjustment can be incorporated in the attenuation spectrum. The resulting modified attenuation spectrum is also shown on Figure 10(b) and it is considered that this curve represents the best estimate of the excess attenuation present in this particular aircraft flyover noise event.

In all frequency bands, the differences were less than the expected 8.8 dB with values ranging between 3.2 dB (at 63 Hz) and 7.6 dB (at 160 Hz). No frequency dependence was evident in the variations from the expected 8.8 dB.



Note: Time scales for the two curves are not correlated.

FIGURE 8. COMPARISON OF OVERHEAD AND SIDELINE FLYOVER TIME HISTORIES

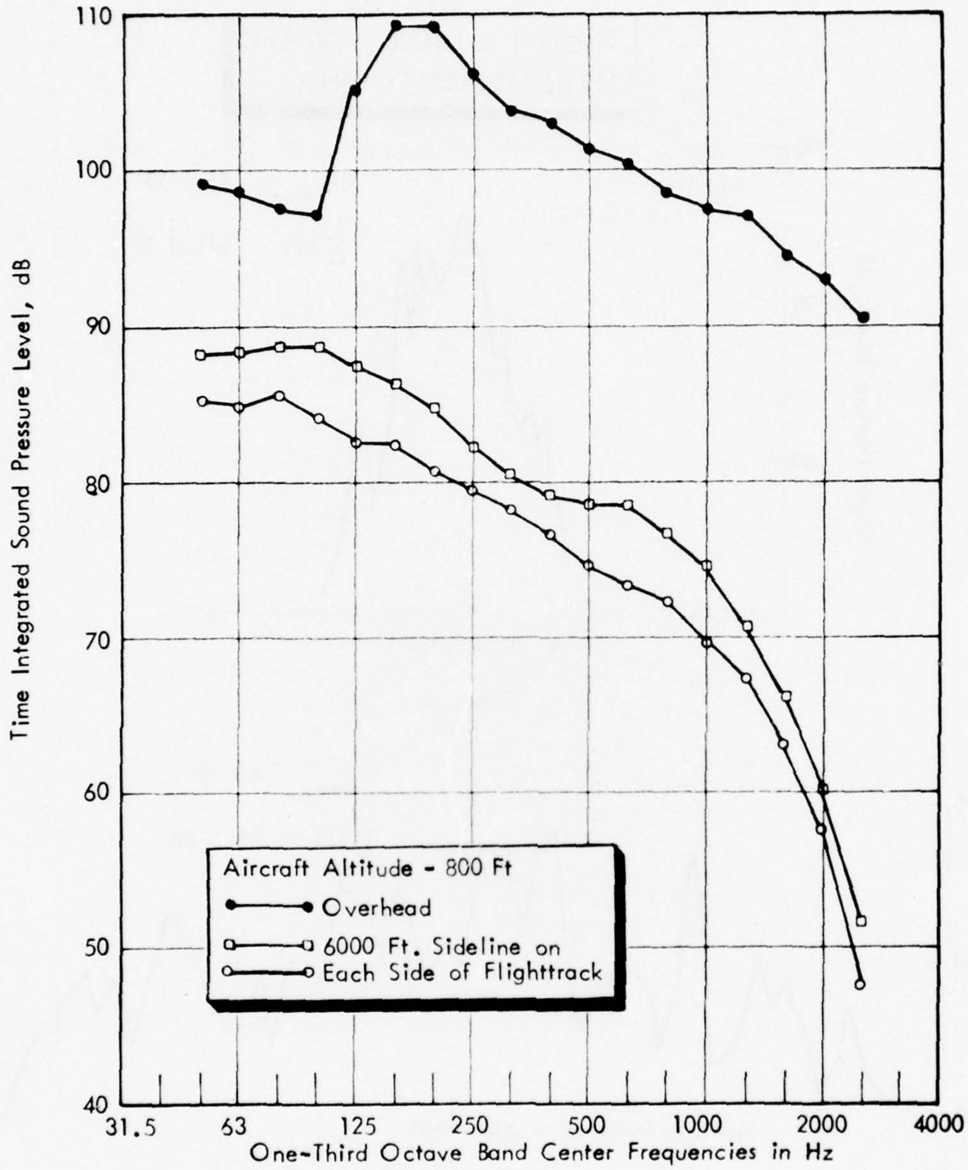
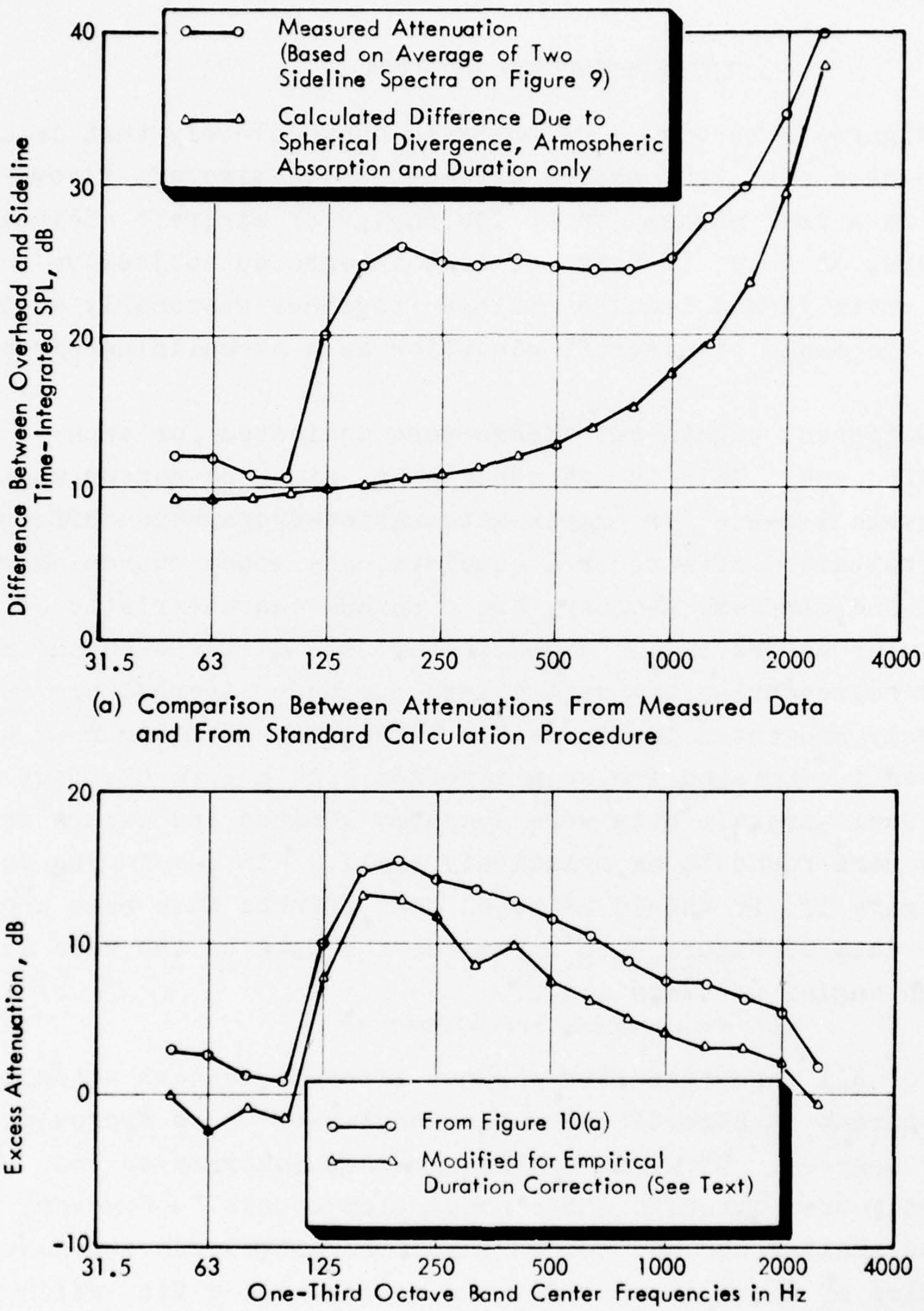


FIGURE 9. TIME INTEGRATED AIRCRAFT FLYOVER SPECTRA



(a) Comparison Between Attenuations From Measured Data and From Standard Calculation Procedure

(b) Sound Energy Attenuation Unaccounted For By Standard Extrapolation Procedures (Excess Attenuation)

FIGURE 10. EXCESS ATTENUATION FROM FLYOVER DATA

INTERPRETATION OF DATA

Figures 2 through 7 demonstrate quite clearly that in all of the data reviewed, excess attenuation of aircraft flyover noise is a real phenomenon at low angles of aircraft elevation. The data, at least in terms of time integrated subjective noise units (EPNL) tend to collapse together reasonably well using the angle of aircraft elevation as a normalizing parameter.

Different functional trends were indicated for each aircraft type. This is not surprising, since no matter what the physical cause for excess attenuation-propagation effects or installation effects or a combination - sound source characteristics and airframe geometry are a unique characteristic of any particular aircraft. To demonstrate these differences the mean curves representing the data points for each aircraft are collectively presented in Figure 11. (The data from Figure 2 have not been interpreted for each aircraft type due to the fact the individual aircraft data were somewhat limited and excess attenuations were found to be relatively small.) In developing curves for Figure 11, it should be noted that offsets have been applied to the data of Figure 3 to normalize the data to the zero axis at high angles of elevation.

For all three and four engined aircraft, excess attenuation was apparent at aircraft elevation angles of up to approximately thirty degrees. This finding is somewhat contrary to the currently used aircraft noise prediction models.[6] However, for the smaller one and two engined aircraft excess attenuation at angles of above 8° tended to be negligible, a fact which is consistent with the current predictive methods.

Since most of the data presented are unique sets, subject to their own idiosyncrasies, comparison between them does involve some risk. However for the 727 airplane, noise data

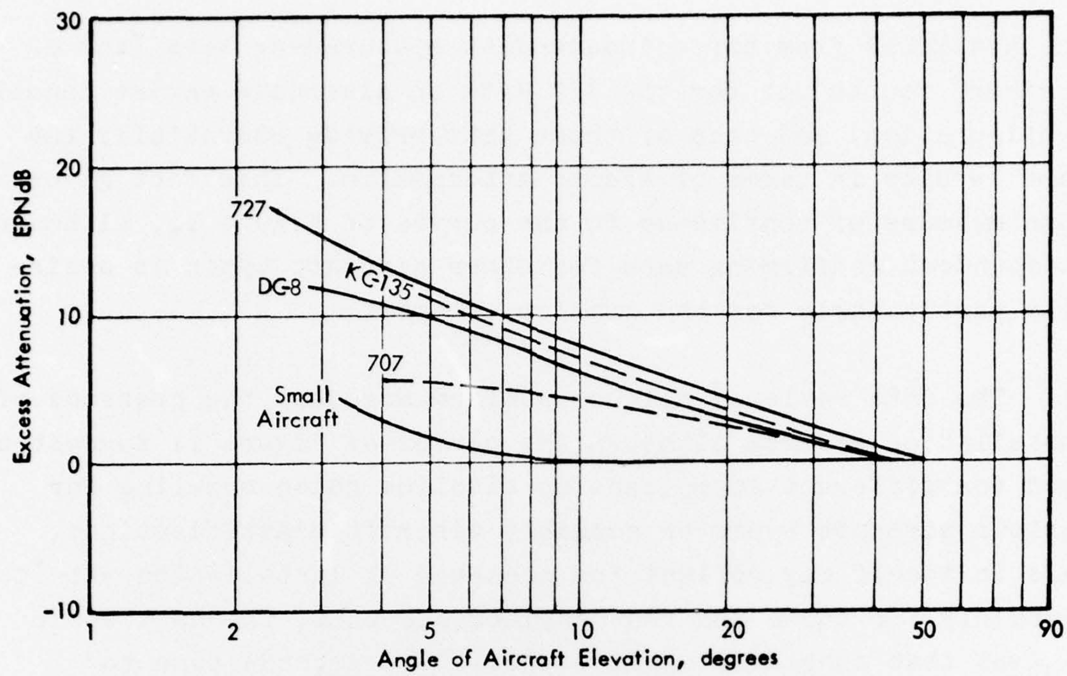


FIGURE 11. EXCESS ATTENUATION AS A FUNCTION OF AIRCRAFT TYPE

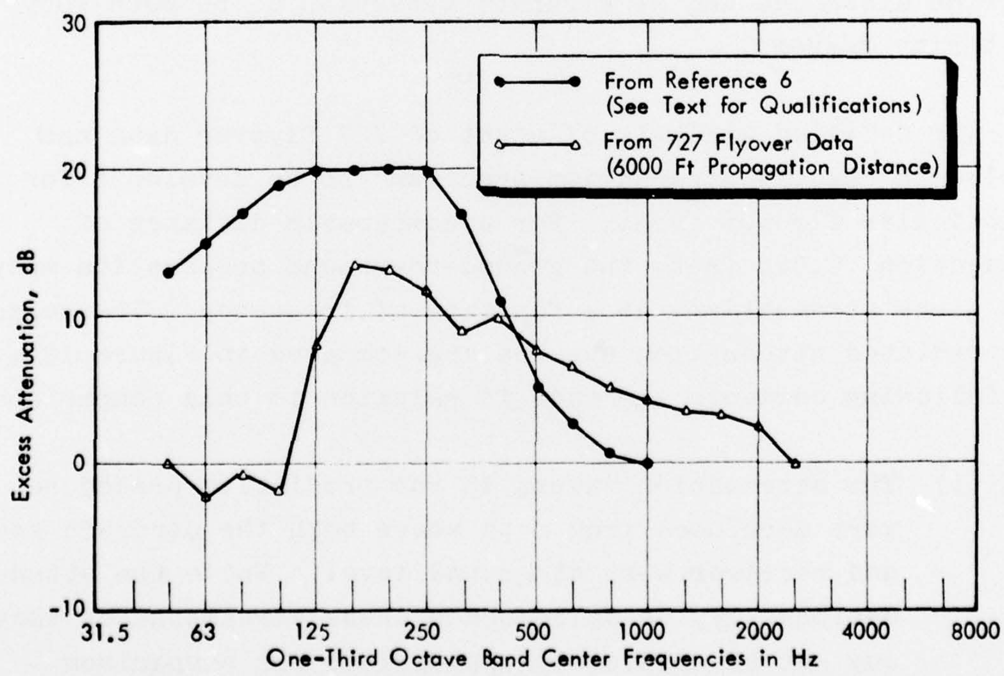


FIGURE 12. COMPARISON OF PREDICTED AND MEASURED AIRCRAFT SIDELINE EXCESS ATTENUATION

are available from three independent measurement sets (and a further, fourth set for the 727 with an alternate engine nacelle configuration) and each of these sets provide essentially the same results in terms of excess attenuation. This fact gives some measure of confidence to the curves of Figure 11, although independent confirming data for other aircraft types is desirable particularly for the smaller aircraft.

The data reviewed neither confirm nor deny the presence of installation effects although the curves of Figure 11 suggest a need for different approaches to sideline noise modeling for various aircraft types or possibly aircraft classifications. This in itself may reflect the presence of installation effects. Certainly for three and four engined aircraft, the data would suggest that currently applied predictive methods tend to overestimate sideline noise levels - particularly at smaller sideline distances and at aircraft elevation of between four and thrity degrees.

The detailed analysis of a set of 727 flyover data has enabled an "excess attenuation spectrum" to be developed for a particular flyover event. For a comparable distance of propagation, 6,000 feet, the ground-to-ground propagation model[6] also gives attenuations as a function of frequency. The measured and predicted attenuation spectra are compared in Figure 12. The following comments are made in relation to this comparison:

(1) The attenuation values in the predictive procedure were developed from data where both the aircraft source and receiver were at ground level. While the attenuations may be valid under these circumstances they may not be completely appropriate for comparison with the data herein where the aircraft was in flight and at 800 feet above ground level.

(2) In the current noise prediction model, (NOISEMAP) ground-to-ground attenuation factors are applied in full only at aircraft elevation angles less than about four degrees and approach zero above seven degrees. Thus, the attenuations shown in Figure 12 would not in fact be applied in this case since the aircraft elevation angle is more than seven degrees.

(3) In the NOISEMAP procedure, an additional 5 dB attenuation is provided to allow for intervening structures on the ground between the source and observer. Since the fly-over data were acquired over open terrain, this 5 dB attenuation factor is not included in this comparison. Further, this 5 dB is empirical and is applied to the overall subjective noise unit (SEL, EPNdB). It is not defined spectrally and thus could not be included in an attenuation spectrum.

Although both attenuation curves in Figure 12 show maximum values between 125 and 315 Hz, the comparison in this instance is not good, particularly in the light of comment (2) above.

More extensive comparisons are required however, before any conlcusive comments may be made concerning the validity of the currently applied ground attenuation factors. This singular evaluation does indicate the potential for some inadequacies in the model and this should encourage a more extensive detailed review with the aim to confirm or update as necessary, current procedures.

There is no doubt that one consclusion may be drawn from the attenuation curve in Figure 11(b). The dramatic onset of excess attenuation at 125 Hz is related in part to the corresponding change in spectrum slope of the overhead flyover spectrum at this frequency shown in Figure 10(a). This characteristic is a result of the acoustic cancellation (at 100 Hz) and reinforcement (at 160-200 Hz) created by the reflection of the flyover signal from the ground surface.[1]

Further, at the sideline position the reflective cancellation (and the resulting SPL minimum) occurs between 400 to 500 Hz based upon the simple geometric relationship between the source and receiver. Thus in a comparison between spectra from the two locations, the different source to receiver geometrics and the resulting reflection effects can very well make a significant contribution to the excess attenuation curve. Additional analysis covering other source and receiver geometric relationships would be necessary to confirm the presence of this reflection effect and its potential magnitude.

In making these comments, it is interesting to note that to the first approximation (excluding source directivity, wind and thermal gradients, and ground characteristics) the form of the acoustic interference phenomenon is a function of source angle of elevation only for a given microphone height. This fact may well contribute to the functional relationship that is demonstrated between the excess attenuation in terms of EPNL and the aircraft angle of elevation.

Atmospheric turbulence has been identified as a possible source of excess attenuation.[16] Unfortunately, the analysis of aircraft flyover data in subjective noise units is too gross

an approach to investigate the presence of attenuation due to turbulent scattering. The detailed analysis of the 727 flyover data however, indicates that the principal trends in excess attenuation (as a funcion of frequency) are not consistent with those estimated for scattering losses. Even though the details of the atmospheric structure are not known in this case, the general trend of scattering losses is one that is constant or increases with frequency.[16] The attenuation spectrum on Figure 12 does not bear this characteristic. While scattering losses may be present, this mechanism does not appear in this instance to be a principal contributor to excess attenuation.

Based upon the limited form of the data available, it is impossible to find evidence that turbulent scattering losses can result in similar excess attenuation charateristics to those effects due to installation or shielding phenomena - which in themselves have yet to be defined.

CONCLUSIONS

The following paragraphs present the conclusions drawn from this technical review of aircraft flyover sideline noise.

All the flyover data reviewed exhibit characteristics of excess attenuation at low angles of aircraft elevation relative to the observer. The degree of attenuation, in terms of subjective noise units, was found to vary considerably with aircraft type.

The excess attenuation term can be presented as a function of aircraft elevation angle only. Although some scatter existed in particular data sets, no consistent trend was found between excess attenuation and source to receiver distance. More complex functional relationships were not investigated.

Three and four engine aircraft demonstrated excess attenuation characteristics up to angles of elevation of 30°. This finding is contrary to current predictive methods where, for all aircraft, excess attenuation becomes negligible above an elevation angle of 7°.

For one specific aircraft, Boeing 727, data from three independent test programs at differing locations demonstrated similar excess attenuation characteristics.

A detailed evaluation of one specific flyover data set gave an excess attenuation spectrum which was not consistent with the values currently used for sideline noise prediction

purposes. The analysis was limited to one case, however, and no generalized conclusion should be drawn. Further, evidence was found that the differing acoustic interference effects caused by sound reflected from the ground surface contributed significantly to the shape of the excess attenuation spectrum.

No positive evidence of installation effects was found in the sideline noise data reviewed. However, the differing excess attenuation characteristics that were found for each aircraft type may well be, at least partially, a result of installation effects.

Though it cannot be stated categorically that atmospheric turbulence does not contribute to the excess attenuation of aircraft noise, no tangible evidence came to light as a result of this study to suggest that turbulence is a significant factor in excess attenuation. There was certainly insufficient detail available in the data analyzed to suggest that attenuation due to turbulence could give rise to effects similar to those that may be anticipated for shielding or installation phenomena.

Current prediction models for sideline noise will tend to overestimate noise levels - - most significantly for three and four engine aircraft. No quantitative evaluation of these overestimations has been made.

Although the data reviewed represents a compendium of available aircraft sideline noise measurements, no doubt exists in the fact that only detailed analysis of flyover information, in physical rather than subjective measures, will provide any understanding of sideline sound propagation phenomena. This analysis approach is considered essential if predictive models for excess attenuation (including installation effects) are to be technically developed.

The summary conclusion of this study is that there is a fundamental need for a review and update of the methods currently used for sideline noise prediction. While a complete understanding of the physics of the problem may not be developed in the near term, it seems feasible that, possibly with additional and more detailed review of existing data, an improvement in the empirical methods used for this element of noise prediction can be achieved. In the long term, however, there is no doubt that the need will exist for an improved understanding in this technical area if the necessary developments are to be achieved in procedures for the prediction of aircraft sideline noise.

RECOMMENDATIONS

Several recommendations are made as a result of the findings of this review.

- Additional sources of detailed flyover data should be pursued and broader based analyses, similar to the 727 flyover analysis undertaken in this report, completed. Alternative analysis approaches can be considered, however, although emphasis must be placed upon the evaluation of the physical trends in the area.

- Any other aircraft data that may be available (in subjective noise units) should be collated with the data of this review. An expansion of the data base will assist the development of purely empirical prediction models. Smaller one and two engine aircraft and four or more engine aircraft, not included in the review, should be emphasized.

- It is not recommended that any changes to the current NOISEMAP procedures be made at the present time. However, the evidence presented by this study suggests that a revised approach to aircraft sideline noise modeling should be investigated. The detailed form of the new model needs to be developed upon a broader data base than presented in this study, however certain elements that should be considered for inclusion in the new model can be recommended.

  - Compute excess attenuation as a function of aircraft angle of elevation only. (Intuition suggests, however, that a form of transition function would still be required for source to receive distances of perhaps less than 1000 feet).

Classify aircraft (1 and 2, and 3 or more engines for example) and apply the appropriate sideline noise model in the evaluation of noise from air base operations.

- The impact of a new sideline noise model on noise contour predictions would need to be assessed in relation to presently used methods. The validity of the new model should also be assessed by comparison with available measurements of air base operations. Only when the new sideline noise model has been developed and appraised, can recommendations be made for changes to the existing NOISEMAP procedure for sideline noise predictions.

- Sources of aircraft noise propagation data where the aircraft is actually at ground level-ground run-up or takeoff roll - should be investigated. If the necessary detail is available in these data then analyses should be undertaken to determine whether similar propagation models to those for low angle of aircraft elevation situations, are appropriate.

- In any experimental program to investigate excess attenuation and/or installation effects, emphasis must be placed on a thorough analysis of the data. Where possible, phased programs in which data from one phase may be used to guide the test plan design of subsequent phases, should be undertaken. Data analysis methods should objectively investigated for value and feasibility prior to the development of any test plans.

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